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EXPERIMENTAL DETERMINATION OF THE HYDRODYNAMIC MASS OF VARIOUS --ETC(U)
JAN 67 R R MILLER, W M HAGIST N70024-1324

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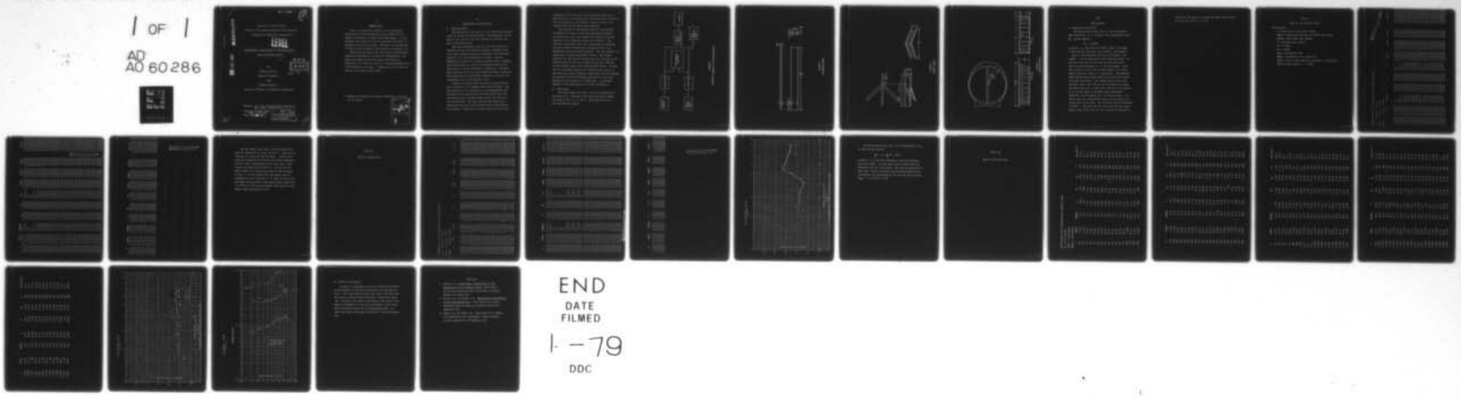

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University of Rhode Island

Division of Engineering Research and Development

Department of Mechanical Engineering

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EXPERIMENTAL DETERMINATION OF THE HYDRODYNAMIC MASS OF VARIOUS BODIES

by

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I

INTRODUCTION

This report gives the results of an experimental determination of the hydrodynamic mass coefficient and damping coefficient for three towed body shapes. It also discusses the results of tests to determine the effect of boundaries near the test body. The work is a continuation of that reported by Hagist (1)* and Miller and Hagist (2).

The towed body shapes were the circular configuration, billboard configuration, and the "Y" configuration. The tests were performed with the bodies oscillating in translation in a vertical plane in a direction perpendicular to the direction of towing. A sphere was used as the test body in the boundary effect tests.

* Numbers in parentheses designate references at the end of the report.

II

EXPERIMENTAL INVESTIGATION

A. Instrumentation

The hydrodynamic mass data for the bodies were obtained using the forced oscillation method. The apparatus was the same as that used for the work reported in reference (2) with some modifications.

The force dynamometer used for the work reported in reference (2) was not sensitive enough to respond to the small forces produced during low frequency, low amplitude operation, so a new dynamometer was built. The new dynamometer consisted of a single stainless-steel octagonal ring instrumented with Kulite semiconductor gages with a gage factor of 58 and temperature compensated. The gages were installed at the U.S. Navy Underwater Sound Laboratory. This dynamometer has sufficient sensitivity and holds its calibration over a long period of time.

During the previous work the force and acceleration were recorded by a two channel strip chart recorder. The date needed for the computation of the hydrodynamic mass consisted of the maximum force exerted on the body, the acceleration, and the phase angle between the force and the acceleration. The force and the phase angle were determined from the recorder traces and the acceleration was computed. Reading the recorder traces was very time

consuming, and if the force and acceleration were small, determination of the phase angle was particularly difficult. The instrumentation was changed to make it read out the maximum force and the phase angle directly.

The read-out of the maximum force was accomplished by letting the output of the force dynamometer charge a low-leakage capacitor and reading the voltage across the capacitor with a standard vacuum tube voltmeter. The read-out of the phase angle was accomplished by measuring the time interval between zero crossings of the force dynamometer and accelerometer signals. The time interval is measured by a Beckman electronic counter. The counter measured the time interval between the zero crossing on the positive slope of the force signal and the zero crossing on the positive slope of the accelerometer signal. To make the zero crossings easy for the counter to see and to be sure that the counter triggered, each signal was put through an amplifier circuit and greatly amplified so that each appeared to the counter as a square wave. A schematic diagram of the instrumentation is shown in Figure 1.

B. Test Bodies

Four test bodies were used. All were constructed of soft pine wood. Drawings of the three towed-body shapes are shown in Figs. 2, 3, and 4. The fourth body was a six inch diameter sphere.

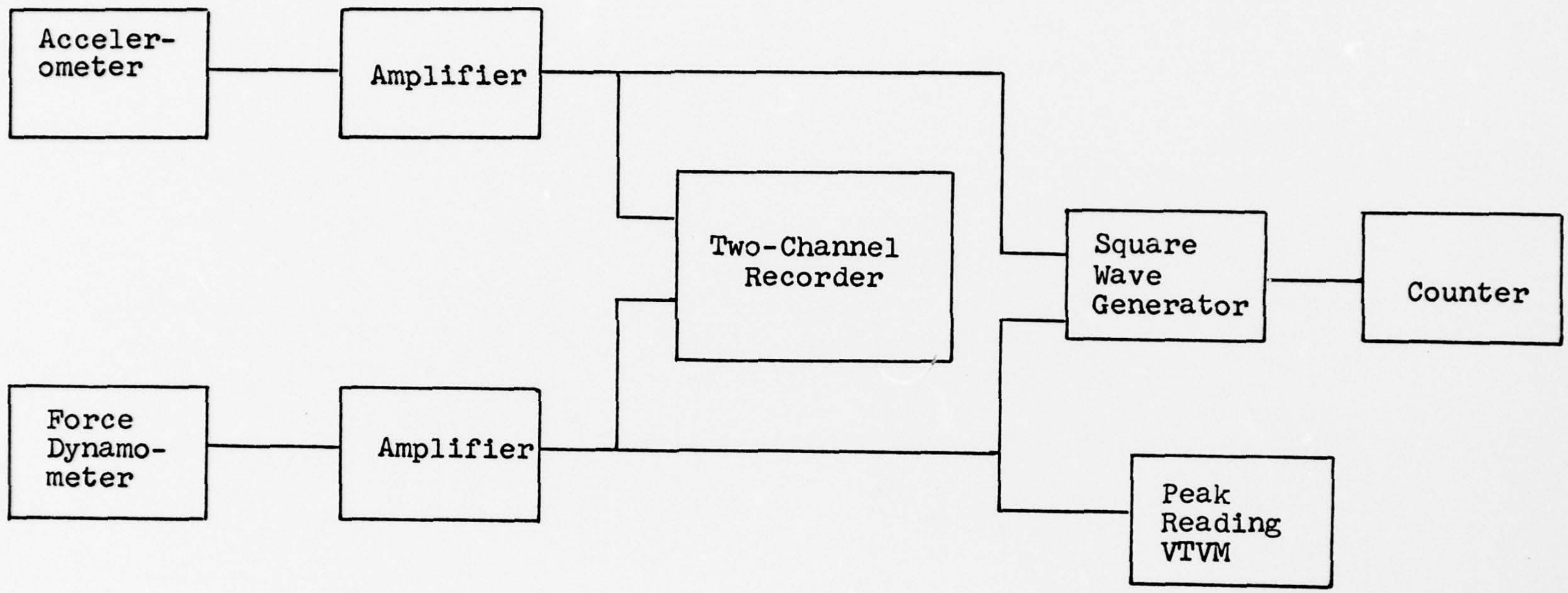


FIGURE 1

Schematic Diagram of Instrumentation

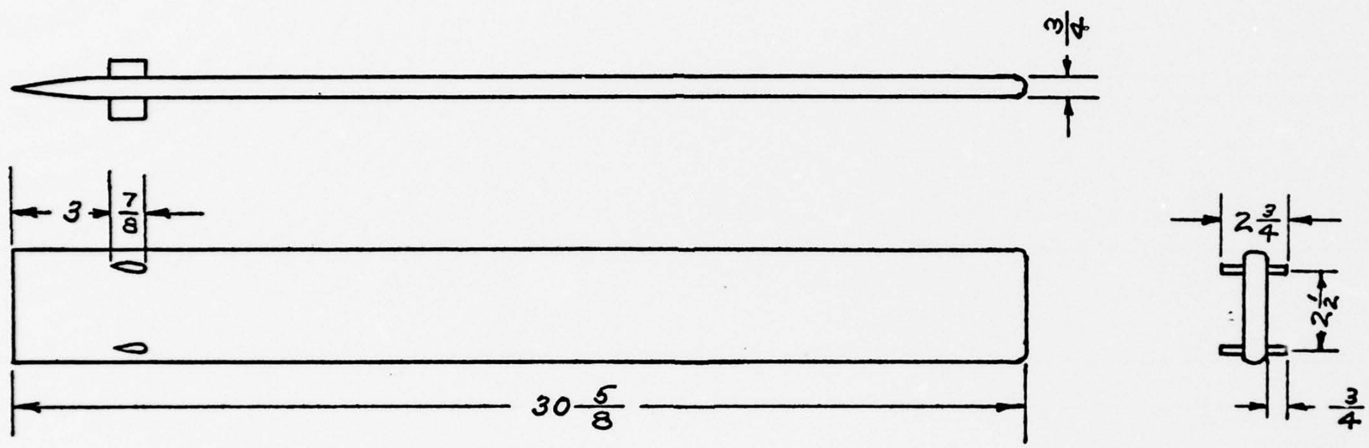


FIGURE 2

BILLBOARD ARRAY

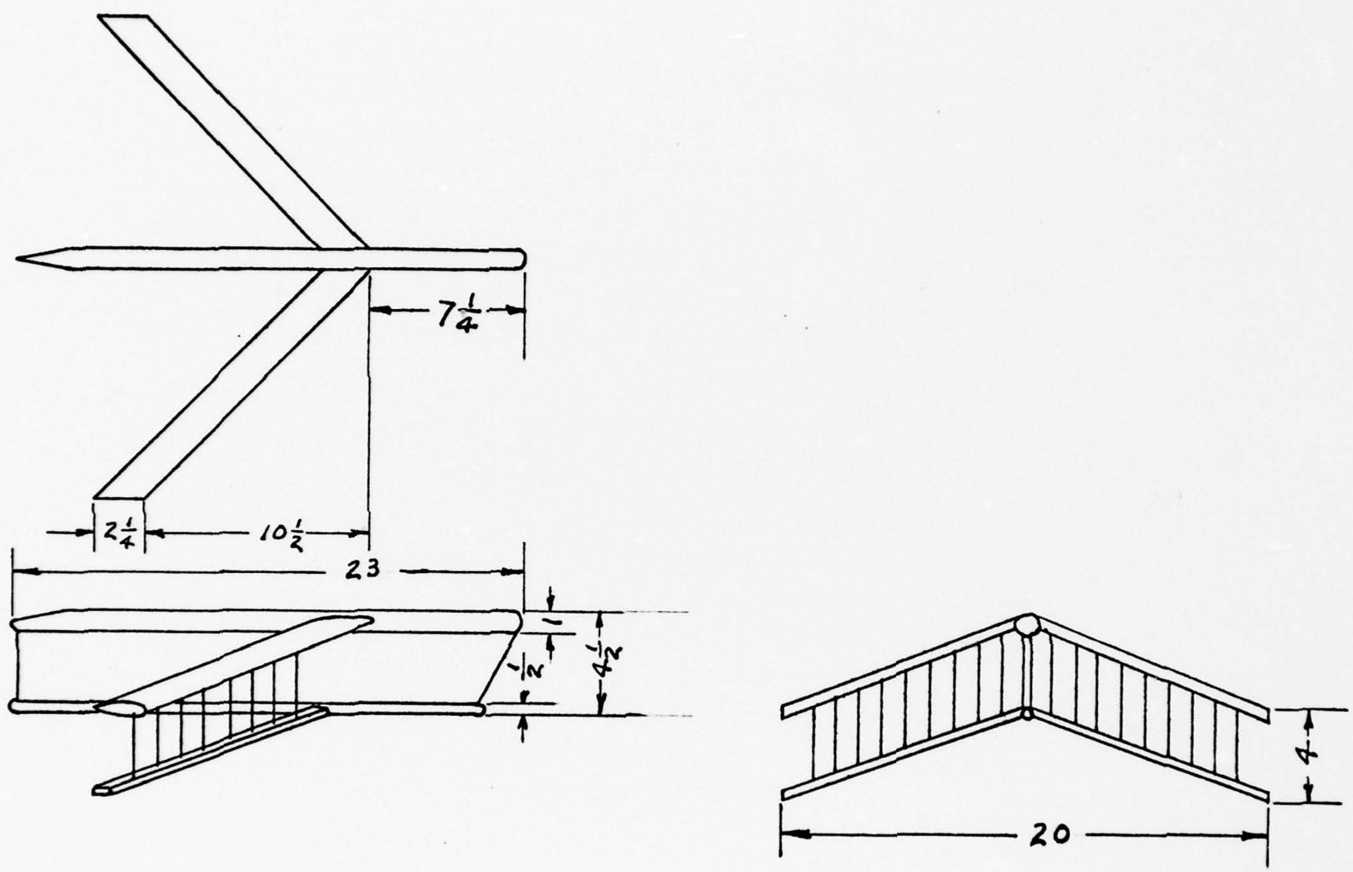


FIGURE 3

WINGED ARRAY

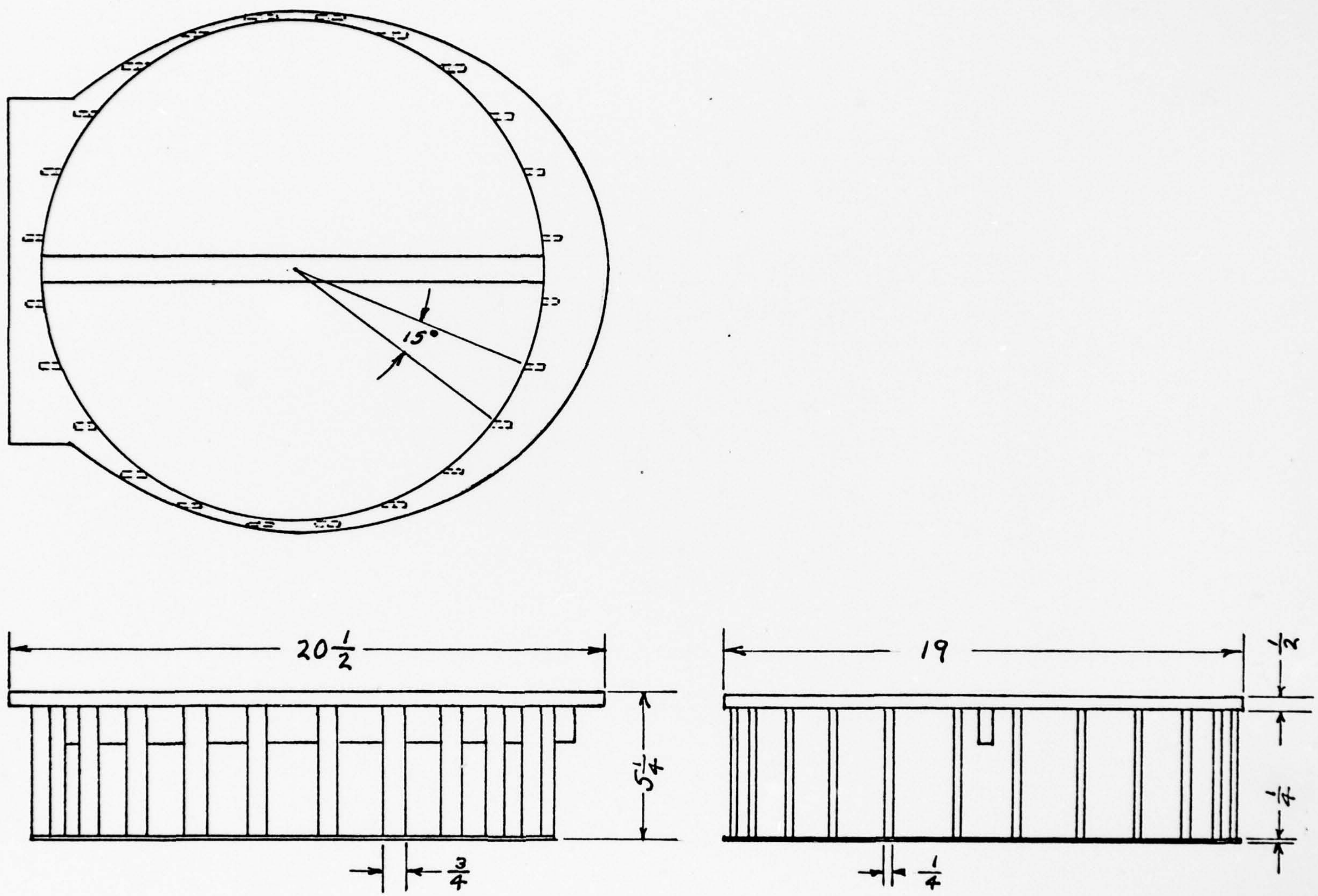


FIGURE 4
CIRCULAR ARRAY

III

TEST RESULTS

A. Hydrodynamic Mass Data

For the billboard array, Fig. 2, the hydrodynamic mass coefficient K is related to the hydrodynamic mass, M_h, by the equation

$$M_h = K \rho lwh$$

in which l, w, and h are the length, width, and height of the body and ρ is the fluid density. The quantity ρlwh is the reference mass of the billboard. The length, l, is the dimension in the towing direction. In the tests the body was oscillated in the heave mode. This is in the direction of h, the body height. Since the billboard is very thin in this direction the hydrodynamic mass and, hence K, is quite small. The measured force and the phase angle between the force and acceleration were quite small. The largest measured force was 10 pounds and in most runs it was less than five pounds. The phase angle was, in most runs, less than five degrees. It is in this range of operation that experimental apparatus, in its present form, is least accurate. As a result there was considerable scatter in the values of K calculated from the data. The billboard data are tabulated in Table I. The best that can be said is that the hydrodynamic mass coefficient for the billboard in the heave

mode is of the order of 0.25 in the Stokes Number range of from 3.5×10^6 to 1.9×10^7.

Table I

Data for the Billboard Array

Nomenclature:

R = amplitude of oscillation, inches

OMEGA = oscillation frequency, ω radians per second

PHIABS = phase angle ϕ , degrees

F = measured force, pounds

FI = F $\cos\phi$

FD = F $\sin\phi$

HYDM = hydrodynamic mass

HYDMK = hydrodynamic mass coefficient

AMPLR = ratio of body length to amplitude of oscillation

STO NO = Stokes Number = $\omega l^2/\nu$

HYDRODYNAMIC MASS CALCULATION FOR BILLBOARD ARRAY

EL = 30.50000 INCHES

REFM = 2.90300 POUNDS

EMASS = 5.97000 POUNDS

R	OMEGA	PHIABS	F	FI	FD	HYDM	HYDMK	AMPLR	STO NO
0.75000	5.990257	0.0	0.45631	0.45631	0.0	0.459925	0.158431	40.6667	0.35179510E 07
0.75000	6.712798	0.0	0.48414	0.48414	0.0	-0.537455	-0.185138	40.6667	0.39422830E 07
0.75000	7.429561	0.0	0.65163	0.65163	0.0	-0.000853	-0.000294	40.6667	0.43632210E 07
0.75000	8.175900	0.64255	0.81130	0.81125	0.00910	0.166532	0.057365	40.6667	0.48015320E 07
0.75000	8.965724	0.0	1.02615	1.02615	0.0	0.484771	0.166990	40.6667	0.52653780E 07
0.75000	9.764071	0.41260	1.22635	1.22632	0.00883	0.534027	0.183957	40.6667	0.57342310E 07
0.75000	10.542248	0.28590	1.42167	1.42166	0.00709	0.497968	0.171536	40.6667	0.61912380E 07
0.75000	11.394958	0.93166	1.69024	1.69001	0.02748	0.611194	0.210539	40.6667	0.66920150E 07
0.75000	12.245526	1.14746	1.95392	1.95353	0.03913	0.617257	0.212627	40.6667	0.71915370E 07
0.75000	13.076336	1.14413	2.25178	2.25134	0.04496	0.687445	0.236805	40.6667	0.76794530E 07
0.75000	13.953319	1.13231	2.56430	2.56380	0.05067	0.688368	0.237123	40.6667	0.81944880E 07
0.75000	14.832813	1.44305	2.82798	2.82708	0.07122	0.527267	0.181628	40.6667	0.87109950E 07
0.75000	15.707165	1.82092	3.06236	3.06082	0.09731	0.303084	0.104404	40.6667	0.92244860E 07
0.75000	16.582672	1.76770	3.24303	3.24149	0.10004	-0.009601	-0.003307	40.6667	0.97386520E 07
0.75000	17.506760	0.13809	3.51160	3.51159	0.00846	-0.176625	-0.060842	40.6667	0.10281348E 08
0.75000	18.425735	0.0	3.90712	3.90712	0.0	-0.151020	-0.052022	40.6667	0.10821042E 08
0.75000	19.374588	6.81294	4.50285	4.47105	0.53416	0.052608	0.018122	40.6667	0.11378283E 08
0.75000	20.333908	4.75630	4.97650	4.95936	0.41264	0.094903	0.032691	40.6667	0.11941673E 08
0.75000	21.298904	1.65254	5.43960	5.43733	0.15687	0.090540	0.031188	40.6667	0.12508395E 08
0.75000	22.264984	1.11652	5.90487	5.90375	0.11506	0.051746	0.017825	40.6667	0.13075753E 08
0.75000	23.228012	1.00462	6.48944	6.48844	0.11378	0.110738	0.038146	40.6667	0.13641320E 08
0.75000	24.184677	1.05334	7.08594	7.08474	0.13026	0.154680	0.053283	40.6667	0.14203147E 08
0.75000	25.152903	0.20657	7.59893	7.59888	0.02740	0.098310	0.033865	40.6667	0.14777638E 08
0.75000	26.114624	1.20274	8.45789	8.45602	0.17753	0.299583	0.103198	40.6667	0.15336566E 08
0.75000	27.106033	2.18896	9.44803	9.44118	0.36087	0.527320	0.181647	40.6667	0.15918801E 08
0.75000	28.037384	1.37390	10.22353	10.22059	0.24513	0.604167	0.208118	40.6667	0.16465762E 08
0.75000	28.994827	1.86945	10.74845	10.74273	0.35064	0.491199	0.169204	40.6667	0.17028048E 08
0.75000	29.948425	1.20782	1.18380	1.18353	0.02495	-5.302773	-1.826653	40.6667	0.17588064E 08
0.75000	30.845261	0.0	1.69509	1.69509	0.0	-5.069142	-1.746173	40.6667	0.18114768E 08

R	OMEGA	PHIABS	F	FI	FD	HYDM	HYDMK	AMPLR	STO NO
0.75000	31.749252	0.0	3.04059	3.04059	0.0	-4.444786	-1.531100	40.6667	0.18645664E 08
0.75000	32.656860	0.74014	3.82098	3.82066	0.04936	-4.158538	-1.432496	40.6667	0.19178672E 08
0.12500	9.780789	0.0	0.19116	0.19116	0.0	0.182280	0.062790	244.0000	0.57440500E 07
0.12500	12.240755	0.0	0.30982	0.30982	0.0	0.396132	0.136456	244.0000	0.71887350E 07
0.12500	14.832813	0.0	0.50025	0.50025	0.0	1.030525	0.354986	244.0000	0.87109950E 07
0.18750	9.780789	0.0	0.29614	0.29614	0.0	0.374650	0.129056	162.6667	0.57440500E 07
0.18750	12.276629	0.00517	0.50514	0.50514	0.00005	0.899147	0.309730	162.6667	0.72098040E 07
0.18750	14.871431	0.0	0.76247	0.76247	0.0	1.095934	0.377518	162.6667	0.87336770E 07
0.25000	9.762553	9.79349	0.41236	0.40635	0.07014	0.574018	0.197733	122.0000	0.57333410E 07
0.25000	12.264648	5.69693	0.68190	0.67853	0.06769	0.953591	0.328485	122.0000	0.72027650E 07
0.25000	14.867911	1.70686	1.02127	1.02081	0.03042	1.117895	0.385083	122.0000	0.87316090E 07
0.31250	9.782312	4.07814	0.50758	0.50629	0.03610	0.516907	0.178059	97.6000	0.57449440E 07
0.31250	12.252689	3.74573	0.81618	0.81444	0.05332	0.681426	0.234732	97.6000	0.71957450E 07
0.31250	14.843326	3.00298	1.22147	1.21979	0.06399	0.818013	0.281782	97.6000	0.87171690E 07
0.37500	9.773183	5.44559	0.60768	0.60494	0.05767	0.491514	0.169312	81.3333	0.57395800E 07
0.37500	12.250300	6.83838	0.99197	0.98491	0.11811	0.725780	0.250010	81.3333	0.71943420E 07
0.37500	14.857365	3.91838	1.46562	1.46219	0.10015	0.787989	0.271439	81.3333	0.87254140E 07
0.43750	9.770144	3.67587	0.70876	0.70730	0.04544	0.500098	0.172269	69.7143	0.57377960E 07
0.43750	12.255080	3.66284	1.13358	1.13126	0.07242	0.607179	0.209156	69.7143	0.71971480E 07
0.43750	14.857365	2.80193	1.71465	1.71260	0.08382	0.804582	0.277155	69.7143	0.87254140E 07
0.50000	9.773183	6.42123	0.85525	0.84988	0.09565	0.818357	0.281901	61.0000	0.57395800E 07
0.50000	12.252689	5.28970	1.32890	1.32324	0.12251	0.754387	0.259865	61.0000	0.71957450E 07
0.50000	14.860880	4.64494	2.01740	2.01077	0.16337	0.976277	0.336299	61.0000	0.87274780E 07
0.56250	9.765588	6.53560	0.93826	0.93216	0.10679	0.648835	0.223505	54.2222	0.57351220E 07
0.56250.	12.252689	6.03214	1.49492	1.48664	0.15710	0.735496	0.253357	54.2222	0.71957450E 07
0.56250	14.846833	5.42703	2.23225	2.22225	0.21112	0.856711	0.295112	54.2222	0.87192290E 07
0.62500	9.779267	9.03541	1.03104	1.01824	0.16192	0.509344	0.175454	48.8000	0.57431560E 07
0.62500	12.252689	6.70437	1.65606	1.64473	0.19334	0.696921	0.240069	48.8000	0.71957450E 07
0.62500	14.853852	5.58511	2.51547	2.50352	0.24482	0.935040	0.322094	48.8000	0.87233530E 07
0.68750	9.767105	9.43444	1.15799	1.14233	0.18982	0.644890	0.222146	44.3636	0.57360120E 07
0.68750	12.243139	7.41816	1.83673	1.82136	0.23714	0.742319	0.255708	44.3636	0.71901340E 07
0.68750	14.871431	6.07752	2.76938	2.75382	0.29320	0.908484	0.312947	44.3636	0.87336770E 07
0.75000	9.764071	6.06294	1.26542	1.25834	0.13365	0.703838	0.242452	40.6667	0.57342310E 07
0.75000	12.252689	4.82761	2.01252	2.00538	0.16937	0.784183	0.270128	40.6667	0.71957450E 07
0.75000	14.846833	4.21796	2.99888	2.99076	0.22057	0.890462	0.306738	40.6667	0.87192290E 07
0.81250	9.767105	0.95023	1.38749	1.38730	0.02301	0.807700	0.278229	37.5385	0.57360120E 07
0.81250	12.252689	1.91747	2.18342	2.18220	0.07306	0.804461	0.277113	37.5385	0.71957450E 07
0.81250	14.850341	2.31697	3.21862	3.21599	0.13012	0.826488	0.284701	37.5385	0.87212890E 07
0.87500	9.767105	3.08139	1.49004	1.48788	0.08010	0.770023	0.265251	34.8571	0.57360120E 07
0.87500	12.240755	3.61707	2.37386	2.36913	0.14976	0.862777	0.297202	34.8571	0.71887350E 07
0.87500	14.839819	2.98465	3.41882	3.41418	0.17801	0.729684	0.251355	34.8571	0.87151120E 07
0.93750	9.774703	6.76234	1.65606	1.64454	0.19500	0.962111	0.331420	32.5333	0.57404740E 07
0.93750	12.238371	6.49174	2.54476	2.52845	0.28771	0.828853	0.285516	32.5333	0.71873360E 07
0.93750	14.867911	4.97743	3.62879	3.61511	0.31485	0.616429	0.212342	32.5333	0.87316090E 07

R	OMEGA	PHIABS	F	FI	FD	HYDM	HYDMK	AMPLR	STO NO
1.00000	9.768624	7.64552	1.81231	1.79620	0.24112	1.126706	0.388118	30.5000	0.57369060E 07
1.00000	12.228843	7.38543	2.72544	2.70282	0.35034	0.844209	0.290806	30.5000	0.71817400E 07
1.00000	14.878473	5.22101	3.90224	3.88605	0.35509	0.648500	0.223390	30.5000	0.87378120E 07
1.25000	9.777745	10.12689	2.32991	2.29361	0.40967	1.224219	0.421708	24.4000	0.57422620E 07
1.25000	12.252689	6.84882	3.35534	3.33140	0.40012	0.684334	0.235733	24.4000	0.71957450E 07
1.25000	14.832813	5.78754	4.78118	4.75681	0.48213	0.513497	0.176885	24.4000	0.87109950E 07
1.50000	9.768624	9.85372	2.72055	2.68042	0.46558	1.008981	0.347565	20.3333	0.57369060E 07
1.50000	12.226463	9.24185	4.19522	4.14076	0.67376	0.912316	0.314267	20.3333	0.71803410E 07
1.50000	14.846833	6.40434	5.95259	5.91544	0.66398	0.697695	0.240336	20.3333	0.87192290E 07
1.75000	9.786883	10.18692	3.09654	3.04773	0.54765	0.767650	0.264433	17.4286	0.57476290E 07
1.75000	12.245526	8.89671	4.78118	4.72365	0.73943	0.700283	0.241227	17.4286	0.71915370E 07
1.75000	14.832813	6.67705	7.34840	7.29855	0.85442	1.054431	0.363221	17.4286	0.87109950E 07
2.00000	9.788408	11.03614	3.70203	3.63357	0.70867	1.016564	0.350177	15.2500	0.57485230E 07
2.00000	12.243139	8.54941	5.67820	5.61510	0.84413	0.931230	0.320782	15.2500	0.71901340E 07
2.00000	14.829312	7.04465	8.33859	8.27564	1.02267	0.962885	0.331686	15.2500	0.87089380E 07

For the winged array (Fig. 3) the reference mass used was determined by taking the sum of ρ lwh for the fuselage and ρ lwh for the two wings. Like the bill-board the winged array was thin in the heave direction and as a result the measured forces were small. The results are tabulated in Table II. As plot of K vs. Stokes Number for an amplitude ratio of 36.8 is shown in Fig. 5. At the present time the authors have no explanation for the behavior of K shown by this curve. One might conclude that in the Stokes Number range from 2×10^6 to 9×10^6 the hydrodynamic mass factor for the winged array approximately 0.25.

Table II

Data for Winged Array

HYDRODYNAMIC MASS CALCULATION FOR WINGED ARRAY

EL = 23.00000 INCHES

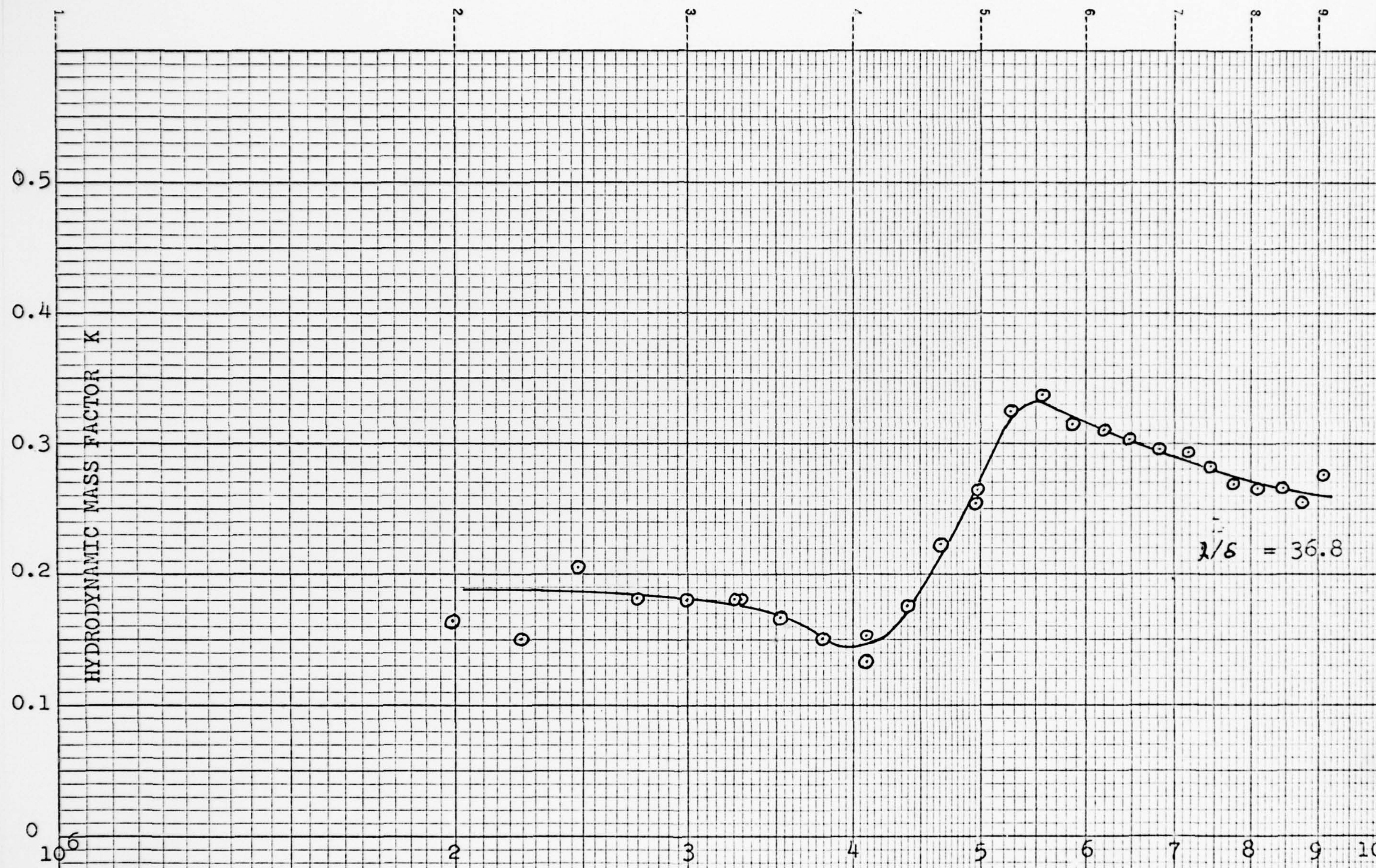
REFM = 10.97000 POUNDS

EMASS = 6.08000 POUNDS

R	OMEGA	PHIABS	F	FI	FD	HYDM	HYDMK	AMPLR	STD ND
0.62500	5.978289	12.17015	0.47437	0.46371	0.10001	1.815653	0.165511	36.8000	0.19965360E 07
0.62500	6.709930	17.33597	0.59889	0.57169	0.17845	1.647049	0.150141	36.8000	0.22408770E 07
0.62500	7.412906	18.68924	0.79714	0.75511	0.25543	2.282278	0.208047	36.8000	0.24756470E 07
0.62500	8.183354	16.86044	0.92849	0.88858	0.26930	1.994703	0.181833	36.8000	0.27329500E 07
0.62500	8.963165	16.35649	1.10916	1.06427	0.31235	1.981627	0.180641	36.8000	0.29933790E 07
0.62500	9.751946	14.79546	1.30448	1.26123	0.33312	1.990579	0.181457	36.8000	0.32568020E 07
0.62500	10.554644	14.05935	1.49492	1.45014	0.36316	1.841641	0.167880	36.8000	0.35248750E 07
0.62500	11.376389	12.61123	1.68536	1.64470	0.36797	1.653378	0.150718	36.8000	0.37993080E 07
0.62500	12.255080	8.54019	1.93439	1.91294	0.28726	1.671071	0.152331	36.8000	0.40927610E 07
0.62500	13.130992	3.63229	2.27620	2.27163	0.14420	1.937416	0.176610	36.8000	0.43852860E 07
0.62500	13.940935	1.45409	2.72544	2.72456	0.06916	2.451094	0.223436	36.8000	0.46557760E 07
0.62500	14.832813	3.90086	3.21862	3.21116	0.21896	2.801937	0.255418	36.8000	0.49536320E 07
0.62500	15.700100	10.42339	3.98525	3.91948	0.72101	3.596462	0.327845	36.8000	0.52432760E 07
0.62500	16.635361	12.96957	4.57121	4.45459	1.02593	3.715723	0.338717	36.8000	0.55556190E 07
0.62500	17.516525	14.27391	4.96240	4.80920	1.22352	3.458265	0.315248	36.8000	0.58498960E 07
0.62500	18.490814	15.21023	5.52311	5.32963	1.44905	3.405881	0.310472	36.8000	0.61752750E 07
0.62500	19.380554	15.68168	6.03610	5.81142	1.63151	3.335488	0.304055	36.8000	0.64724160E 07
0.62500	20.366867	16.26855	6.63260	6.36702	1.85805	3.260732	0.297241	36.8000	0.68018110E 07
0.62500	21.313354	16.11330	7.22910	6.94510	2.00634	3.223955	0.293888	36.8000	0.71179030E 07
0.62500	22.280777	15.57233	7.76595	7.48088	2.08480	3.090328	0.281707	36.8000	0.74409880E 07
0.62500	23.219437	15.31551	8.30280	8.00793	2.19305	2.958785	0.269716	36.8000	0.77544680E 07
0.62500	24.203308	15.10062	8.97088	8.66111	2.33704	2.917396	0.265943	36.8000	0.80830450E 07
0.62500	25.162903	11.36707	9.57931	9.39141	1.88802	2.946141	0.268563	36.8000	0.84035160E 07
0.64500	26.136353	11.02046	10.45020	10.25748	1.99765	2.770344	0.252538	35.6589	0.87286150E 07
0.62500	27.082657	9.42587	11.16600	11.01524	1.82867	3.059122	0.278863	36.8000	0.90446470E 07
0.62500	28.049896	9.17321	1.80273	1.77967	0.28739	-4.703518	-0.428762	36.8000	0.93676700E 07
0.62500	28.981445	7.41330	2.58312	2.56153	0.33329	-4.224113	-0.385060	36.8000	0.96787740E 07
0.62500	29.948425	5.60182	3.55188	3.53491	0.34671	-3.681587	-0.335605	36.8000	0.10001712E 08
0.62500	30.875565	4.17839	4.95120	4.93804	0.36075	-2.927773	-0.266889	36.8000	0.10311344E 08
0.18750	9.789933	38.17668	0.37427	0.29422	0.23133	0.211624	0.019291	122.6667	0.32694900E 07

R	OMEGA	PHIABS	F	FI	FD	HYDM	HYDMK	AMPLR	STO NO
0.18750	12.264648	349.85059	0.51344	0.50540	-0.09048	0.806204	0.073492	122.6667	0.40959560E 07-
0.18750	14.857365	0.0	1.25565	1.25565	0.0	5.578372	0.508512	122.6667	0.49618310E 07
0.25000	9.754975	343.54443	0.49781	0.47742	-0.14102	1.620520	0.147723	92.0000	0.32578150E 07-
0.25000	12.262255	0.0	0.68923	0.68923	0.0	0.955439	0.087096	92.0000	0.40951580E 07
0.25000	14.860880	0.0	1.59746	1.59746	0.0	5.022277	0.457819	92.0000	0.49630050E 07
0.31250	9.779267	0.0	0.63063	0.63063	0.0	2.005006	0.182772	73.6000	0.32659280E 07
0.31250	12.259862	0.0	0.87966	0.87966	0.0	1.095689	0.099880	73.6000	0.40943580E 07
0.31250	14.892580	0.0	1.90997	1.90997	0.0	4.478591	0.408258	73.6000	0.49735930E 07
0.37500	9.792985	0.0	0.75905	0.75905	0.0	1.994913	0.181852	61.3333	0.32705090E 07
0.37500	12.262255	0.0	1.07498	1.07498	0.0	1.213842	0.110651	61.3333	0.40951580E 07
0.37500	14.864394	0.0	2.17854	2.17854	0.0	3.979278	0.362742	61.3333	0.49641790E 07
0.43750	9.785359	2.95714	0.90896	0.90775	0.04689	2.197933	0.200359	52.5714	0.32679610E 07
0.43750	12.259862	0.14311	1.26542	1.26541	0.00316	1.271406	0.115898	52.5714	0.40943580E 07
0.43750	14.885525	0.0	2.47640	2.47640	0.0	3.678926	0.335362	52.5714	0.49712360E 07
0.50000	9.803681	3.96942	1.03592	1.03343	0.07171	2.123173	0.193544	46.0000	0.32740800E 07
0.50000	12.267042	1.42473	1.43632	1.43588	0.03571	1.199739	0.109365	46.0000	0.40967550E 07
0.50000	14.860880	0.0	2.71079	2.71079	0.0	3.284489	0.299406	46.0000	0.49630050E 07
0.56250	9.786883	6.49533	1.20682	1.19908	0.13652	2.397058	0.218510	40.8889	0.32684710E 07
0.56250	12.252689	2.55740	1.70489	1.70319	0.07607	1.602234	0.146056	40.8889	0.40919630E 07
0.56250	14.860880	0.0	3.02818	3.02818	0.0	3.204959	0.292157	40.8889	0.49630050E 07
0.62500	9.785359	7.53037	1.28007	1.26903	0.16775	1.985103	0.180957	36.8000	0.32679610E 07
0.62500	12.262255	3.22484	1.86603	1.86307	0.10497	1.460177	0.133106	36.8000	0.40951580E 07
0.62500	14.867911	0.97886	3.26745	3.26706	0.05012	2.913948	0.265629	36.8000	0.49653550E 07
0.68750	9.783835	10.38293	1.42167	1.39839	0.25622	1.990025	0.181406	33.4545	0.32674530E 07
0.68750	12.274233	4.07983	2.13459	2.12918	0.15183	1.727069	0.157436	33.4545	0.40991560E 07
0.68750	14.857365	3.07462	3.61902	3.61381	0.19411	2.963689	0.270163	33.4545	0.49618310E 07
0.75000	9.768624	11.15074	1.55840	1.52898	0.30138	2.021662	0.184290	30.6667	0.32623730E 07
0.75000	12.259862	4.70664	2.32991	2.32205	0.19118	1.731616	0.157850	30.6667	0.40943580E 07
0.75000	14.871431	4.95917	3.96083	3.94601	0.34240	2.941769	0.268165	30.6667	0.49665300E 07
0.81250	9.788408	13.73518	1.71465	1.66562	0.40712	2.022057	0.184326	28.3077	0.32689800E 07
0.81250	12.245526	6.82547	2.55453	2.53643	0.30359	1.803341	0.164388	28.3077	0.40895700E 07
0.81250	14.846833	7.91872	4.27823	4.23743	0.58940	2.879389	0.262478	28.3077	0.49583140E 07
0.87500	9.802152	16.57939	1.87579	1.79781	0.53525	2.005840	0.182848	26.2857	0.32735690E 07
0.87500	12.259862	9.14615	2.82798	2.79202	0.44952	1.947354	0.177516	26.2857	0.40943580E 07
0.87500	14.874950	10.04830	4.72258	4.65014	0.82399	3.001963	0.273652	26.2857	0.49677040E 07
0.93750	9.799094	19.29825	2.04182	1.92709	0.67479	2.002741	0.182565	24.5333	0.32725480E 07
0.93750	12.259862	11.23531	3.12584	3.06594	0.60903	2.135249	0.194644	24.5333	0.40943580E 07
0.93750	14.853852	12.78085	5.29644	5.16521	1.17169	3.348413	0.305234	24.5333	0.49606600E 07
1.00000	9.774703	22.91499	2.18831	2.01561	0.85205	1.873682	0.170801	23.0000	0.32644030E 07
1.00000	12.252689	13.53853	3.40417	3.30958	0.79691	2.231475	0.203416	23.0000	0.40919630E 07
1.00000	14.846833	14.72268	5.76171	5.57253	1.46428	3.451325	0.314615	23.0000	0.49583140E 07

R	OMEGA	PHIABS	F	FI	FD	HYDM	HYDMK	AMPLR	STO NO
1.12500	9.768624	23.85222	2.49593	2.28276	1.00930	1.913723	0.174451	20.4444	0.32623730E 07
1.12500	12.252689	16.03087	3.99013	3.83497	1.10189	2.455999	0.223883	20.4444	0.40919630E 07
1.12500	14.850341	16.98192	6.85927	6.56018	2.00338	3.860275	0.351894	20.4444	0.49594860E 07
1.25000	9.802152	25.63965	2.83774	2.55832	1.22792	1.904598	0.173619	18.4000	0.32735690E 07
1.25000	12.250300	18.53281	4.52726	4.29249	1.43898	2.497413	0.227658	18.4000	0.40911660E 07
1.25000	14.850341	19.45142	7.90911	7.45769	2.63379	4.060811	0.370174	18.4000	0.49594860E 07
1.37500	9.771664	27.65088	3.15514	2.79480	1.46424	1.876238	0.171034	16.7273	0.32633880E 07



STOKES NUMBER $\omega l^2/\nu$

FIGURE 5

HYDRODYNAMIC MASS FACTOR FOR THE WINGED ARRAY

For the circular array (Fig. 4) the hydrodynamic mass is given by the equation

$$M_h = K\pi \frac{\rho}{4}(b^2 - a^2)h$$

in which b is the outer diameter, a the inner diameter and h the height. For the model used in these tests the reference mass was 11.86 pounds. The data are tabulated in Table III. Figure 6 indicates that the hydrodynamic mass coefficient K is approximately 0.82 over the Stokes number range 1.5×10^6 to 8×10^6.

Table III

Data for Circular Array

Hydrodynamic Mass Calculation for Circular Array

EL = 18.75 inches

REFM = 11.86 pounds

EMASS = 4.29 pounds

R	OMEGA	PHIABS	F	FI	M_h	K	STO NO$\times 10^{-5}$
.25	7.431	3.6	.485	.484	9.08	.766	16.49
.25	9.781	4.3	.88	.876	9.68	.816	21.7
.25	12.26	4.3	1.41	1.40	9.93	.837	27.2
.25	14.84	4.7	1.99	1.98	9.44	.796	32.94
.25	17.56	5.5	2.93	2.91	10.11	.853	38.97
.25	19.43	6.1	3.62	3.60	10.31	.869	43.12
.25	21.33	6.7	4.23	4.20	9.80	.826	47.34
.25	23.25	6.0	4.86	4.83	9.35	.788	51.6
.25	25.21	5.6	5.98	5.94	10.06	.848	55.95
.25	27.13	6.4	6.74	6.69	9.59	.809	60.21
.25	29.05	6.7	7.71	7.66	9.57	.807	64.47
.25	30.89	6.5	8.79	8.73	9.68	.816	68.56
.25	32.71	6.5	9.51	9.44	9.18	.774	72.6
.375	9.786	10.2	1.34	1.32	9.71	.819	21.72
.375	12.28	10.5	2.11	2.08	9.71	.819	27.25
.375	14.88	10.4	3.02	2.97	9.33	.787	33.03
.500	5.327	5.6	.545	.542	10.20	.860	11.82

R	OMEGA	PHIABS	F	FI	M_h	K	STO NO$\times 10^{-5}$
.500	7.434	13.2	1.06	1.04	10.00	.843	16.5
.500	9.782	14.5	1.85	1.79	9.91	.836	21.7
.500	12.25	13.5	2.83	2.75	9.61	.810	27.2
.500	13.98	12.9	3.68	3.59	9.65	.814	31.03
.500	15.74	13.1	4.73	4.61	9.84	.829	34.93
.500	17.56	14.0	5.78	5.61	9.52	.803	38.97
.500	19.42	14.5	7.21	6.98	9.76	.823	43.1
.500	21.30	11.1	8.79	8.61	10.11	.852	47.27
.500	23.24	20.1	12.97	12.17	12.91	1.09	51.58
.500	25.19	21.5	14.28	13.28	11.58	.976	55.9
.500	27.11	20.1	15.12	14.18	10.35	.873	60.17
.500	29.05	18.8	16.72	15.82	9.94	.838	64.48
.500	30.88	17.7	18.4	17.34	9.50	.801	68.54
.625	9.801	18.75	2.38	2.25	9.89	.834	21.75
.625	12.24	18.8	3.65	3.46	9.70	.818	27.17
.625	14.85	18.1	5.20	4.94	8.72	.735	32.96
.750	5.302	17.8	1.01	.963	10.32	.870	11.77
.750	7.411	21.5	1.97	1.83	9.41	.793	16.45
.750	9.746	21.2	3.50	3.26	9.92	.836	21.63
.750	12.23	19.9	5.70	5.36	10.69	.901	27.14
.750	13.96	20.0	7.62	7.16	11.12	.938	30.98

R	OMEGA	PHIABS	F	FI	M_h	K	STO NO$\times 10^{-5}$
.75	15.72	19.2	9.98	9.42	11.82	.996	34.89
.75	17.57	21.9	12.80	11.88	12.02	1.013	38.99
.75	19.42	24.3	15.98	14.56	12.06	1.017	43.1
.75	21.27	31.4	18.27	15.60	9.99	.842	47.2
.75	23.23	36.2	21.93	17.6	9.05	.763	51.56
.875	9.781	28.7	4.41	3.88	10.08	.85	21.7
.875	12.24	27.8	7.29	6.47	11.23	.947	27.2
.875	14.84	29.0	11.70	10.24	13.65	1.15	32.94
1.00	9.785	35.4	5.43	4.43	10.00	.843	21.7
1.00	12.20	33.6	9.03	7.52	11.60	.978	27.1
1.00	14.84	33.1	13.43	11.25	11.81	.996	32.94
1.0625	9.779	36.3	5.70	4.59	9.56	.866	21.7
1.0625	12.24	34.6	9.18	7.56	10.43	.879	27.2
1.0625	14.84	35.1	14.41	11.79	11.52	.971	32.94
1.125	9.805	38.1	6.37	5.01	9.97	.841	21.76
1.125	12.22	36.2	11.3	9.12	12.95	1.092	27.12
1.125	14.85	37.1	15.25	12.15	10.96	.924	32.96
1.1875	9.796	39.6	6.79	5.23	9.79	.825	21.74
1.1875	12.23	36.9	11.68	9.34	12.28	1.035	27.14
1.1875	14.83	38.5	16.62	13.01	11.25	.948	32.9
1.250	9.788	40.4	7.26	5.53	9.87	.832	21.7

R	OMEGA	PHIABS	F	FI	M_h	K	STO NO$\times10^{-5}$
1.250	12.23	38.5	12.35	9.67	11.92	1.005	27.14
1.250	14.80	38.8	17.65	13.77	11.40	.961	32.85
1.3125	9.769	39.5	7.88	6.08	11.72	.988	21.68
1.3125	12.22	39.9	13.20	10.14	11.95	1.008	27.2
1.3125	14.83	39.7	18.88	14.54	11.40	.961	32.9
1.3750	9.773	42.1	8.45	6.27	10.40	.877	21.69
1.3750	12.23	41.1	14.03	10.58	11.78	.993	27.1
1.3750	14.84	40.3	19.4	14.80	10.82	.912	32.94
1.4375	9.752	40.5	9.12	6.93	11.47	.967	21.64
1.4375	12.24	40.1	14.86	11.37	12.30	1.04	27.17
1.4375	14.81	39.2	20.8	16.12	11.63	.981	32.87
1.500	9.750	40.7	9.48	7.19	11.34	.956	21.64
1.500	12.24	40.3	14.58	11.12	11.00	.927	27.17
1.500	14.80	40.6	21.4	16.24	10.96	.924	32.85
1.5625	9.755	41.4	9.95	7.46	11.23	.947	21.65
1.5625	12.23	40.0	15.2	11.64	11.08	.934	27.14
1.5625	14.82	40.1	22.4	17.14	11.15	.940	32.89
1.6250	9.760	41.8	11.0	8.19	12.21	1.02	21.66
1.6250	12.22	42.1	15.9	11.80	10.62	.895	27.1
1.6250	14.80	41.3	23.55	17.69	11.02	.929	32.85
1.6875	9.750	43.6	10.10	7.32	9.49	.800	21.64

R	OMEGA	PHIABS	F	FI	M_h	K	STO NO $\times 10^{-5}$
1.6875	12.26	43.2	16.8	12.26	10.50	.885	27.2
1.6875	14.79	41.2	24.27	18.28	10.94	.923	32.8
1.750	9.795	42.9	10.85	7.95	10.11	.852	21.74
1.750	12.28	40.5	17.40	13.22	11.12	.938	27.25
1.750	14.82	41.9	25.8	19.22	11.10	.936	32.89
1.8125	9.752	43.9	11.43	8.24	10.25	.864	21.64
1.8125	12.22	43.0	18.51	13.53	11.05	.932	27.12
1.8750	9.752	44.4	11.88	8.49	10.15	.856	21.64
1.8750	12.25	42.5	19.35	14.26	11.28	.951	27.19
1.9375	9.758	44.6	13.00	9.26	11.07	.933	21.65
1.9375	12.21	43.0	20.45	14.95	11.66	.983	27.1
2.000	9.740	45.2	13.46	9.49	10.98	.926	21.6
2.000	12.27	43.1	21.55	15.73	11.80	.995	27.23

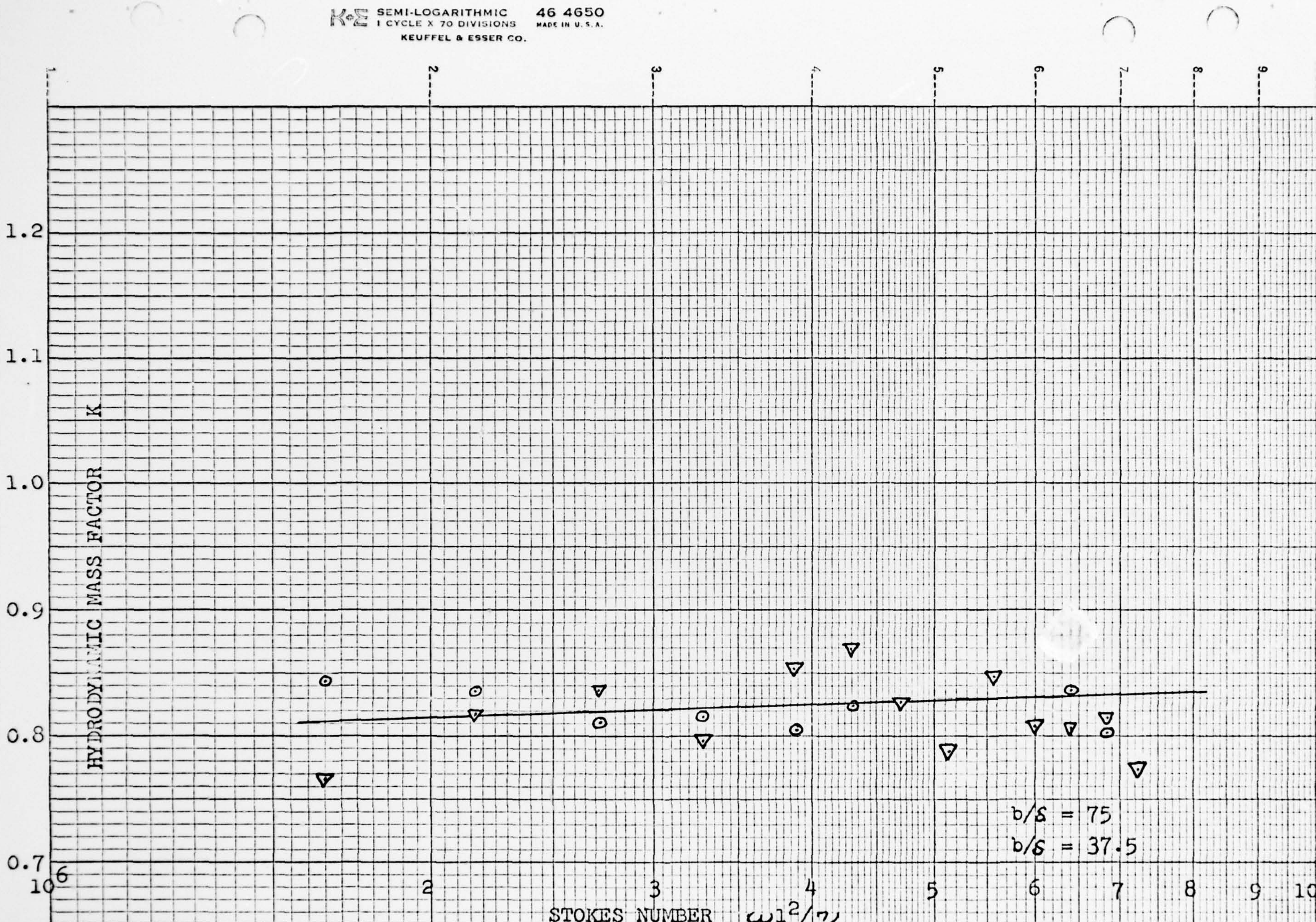
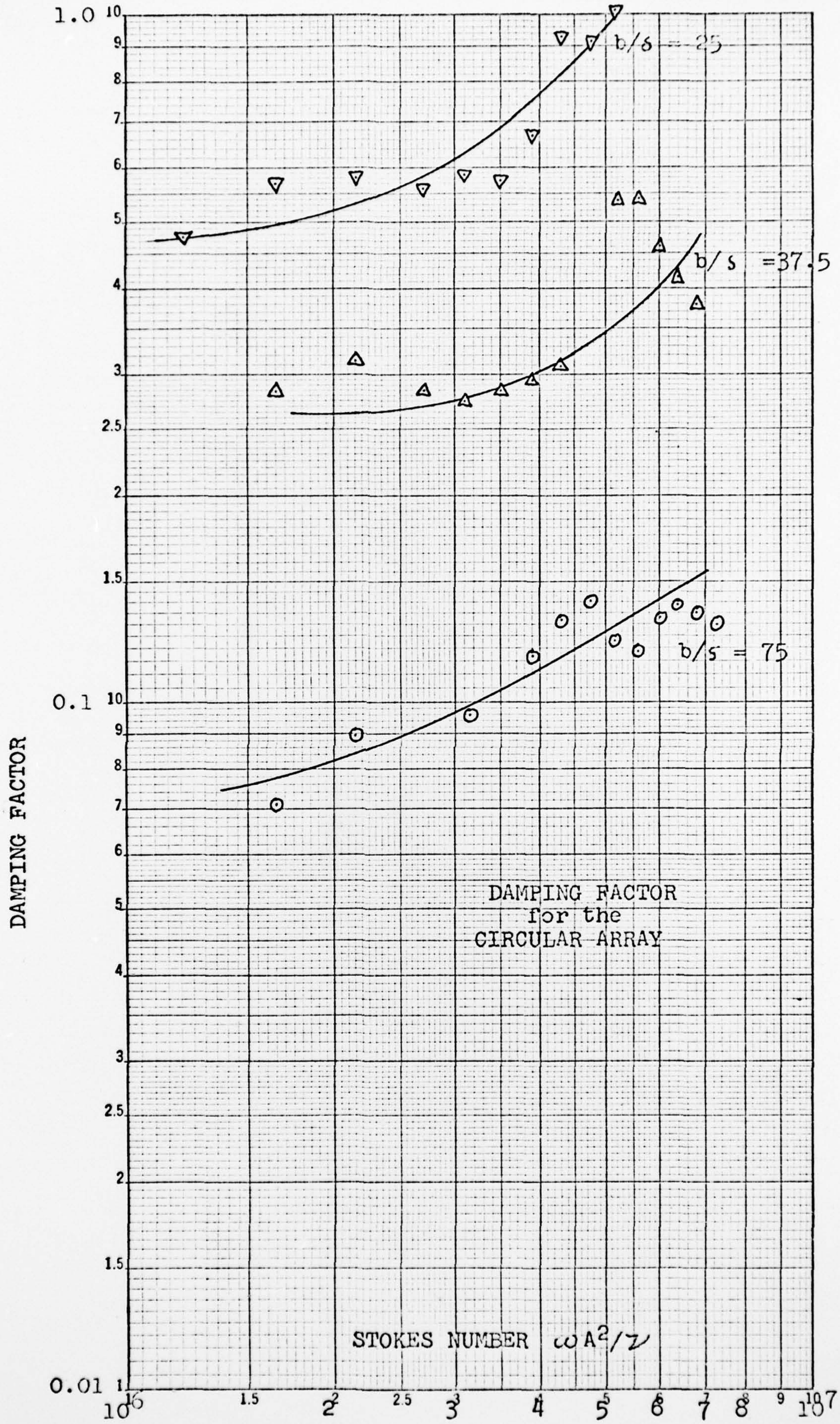


FIGURE 6

HYDRODYNAMIC MASS FACTOR FOR CIRCULAR ARRAY


DAMPING FACTOR
for the
CIRCULAR ARRAY
b/s = 25
b/s = 37.5
b/s = 75
DAMPING FACTOR
STOKES NUMBER $\omega A^2/\nu$
1.0
0.1
0.01
10^6
2
3
4
5
6
7
8
10^7

B. Effect of Boundaries

A series of experiments was run to determine the effect of the nearness of the bottom boundary on the hydrodynamic mass. A six inch diameter sphere was used as the test body. The results obtained concur with those of Bayse and Young (3). As long as the ratio of the depth of the water to the depth of submergence of the body was between 2 and 7 there was no noticeable effect on the hydrodynamic mass. No tests were made to determine the effect of the side boundaries.

References

1. Hagist, W.M., Experimental Determination of the Hydrodynamic Mass of Various Bodies, Final Report to U.S. Navy Underwater Sound Laboratory on Contract N70024-1024, March 1965.

2. Miller, R.R. and Hagist, W.M., Experimental Determination of the Hydrodynamic Mass, Final Report to U.S.Navy Underwater Sound Laboratory on Contract N70024-1162, September 1965.

3. Bayse, C.B. and Young, D.V., "Oscillations of a Sphere in a Cylindrical Tube Containing a Viscous Liquid", A.S.M.E. preprint No. 66-WA/UNT-5, 1966.